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The need for the evaluation of the adhesive bonding systems for the Medical Unit, Self-Contained, Transportable inflatable shelter under extreme environmental temperatures, 94°C (200°F) in the desert and −46°C (−50°F) in the arctic, results from the failures found when new shelters were erected in the field. Some of the observed failures, which would seriously affect the performance of the shelters in the field, could be traced to poor adhesive bonding.

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20. Abstract (cont'd)

It was found that the two adhesives, Bostik 1039/5 and Bostik 1095/9, could be used successfully in bonding seams in MUST shelters for low temperature use. However, the adhesive Bostik 1095/9 is stiffer and more brittle when subjected to low temperatures than the adhesive Bostiik 1039/5. This increase in stiffness and brittleness is reflected in MUST shelters by an increase in storage volume and an increased propensity for seam separation when compared with an identical MUST unit made with adhesive Bostik 1039/5.

PREFACE

This work was accomplished in-house under a Production Engineering Program for OPA-funded items for the MUST shelters. Appreciation is expressed for the support given to the active conduct of the test by the following personnel:

Ernest E. Saab	Equipment Specialist (Tentage)
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All tests were conducted in the Sir Hubert Wilkens Arctic Test Chamber at the US Army Natick Research and Development Command (NARADCOM). NARADCOM has also been known as the US Army Natick Laboratories (NLABS), and the US Army Natick Development Center (NDC).

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A COLD TEMPERATURE EVALUATION OF THE BONDING ADHESIVES USED FOR THE MUST INFLATABLE SHELTERS

INTRODUCTION

The need for the evaluation of the adhesive bonding systems for the Medical Unit Self-Contained, Transportable (MUST) inflatable shelters results from various failures which occurred when shelters from current procurements were erected in the field. The failures found in new MUST inflatable shelters were brought into sharp focus at the Initial Production Test (IPT) held at Fort Sam Houston, San Antonio, Texas, 23–27 April 1973.[1] Representatives of the Office of The Surgeon General (OTSG), TROSCOM, and NARADCOM met to examine the initial production of three new MUST inflatable corridor connectors. The numerous failures observed in the three shelters forced the examining team to conclude that the shelters were unfit for an IPT evaluation. Some of the observed failures, which would seriously affect the performance of the shelters in the field, could be traced to poor adhesive bonding. Hence, the need for evaluating the relative merits of the adhesive systems used in the shelter was obvious. Further, the evaluation of the bonding systems needs to be conducted under the extreme temperature conditions which field shelters would be subjected to, a high skin temperature of 94°C (200°F) in the desert and a low temperature of −46°C (−50°F) in the arctic.

OBJECTIVE:

The objective of this report is to first review briefly the background of MUST shelters successfully used in the field, and then to report the cold temperature test conducted on MUST shelters selected from current production. The review will include information concerning the adhesives used in the MUST shelters, from both past and recent laboratory tests conducted on the adhesives, and prior cold temperature tests conducted on the MUST shelter units.

A description of the high temperature tests is beyond the scope of this report. The National Bureau of Standards has already completed the high temperature study on the current production of MUST inflatable shelters and issued a separate report.[2]

[1] Report of Travel of Renzo Monti dated 3 May 1973, A Visit to the Medical Test and Evaluation Detachment to Participate with Surgeon General Personnel in Witnessing the Initial Production Test (IPT) of Inflatable Shelter and Corridor Connector Sections and Passage Ways, Fort Sam Houston, San Antonio, Texas, 23–27 April 1973.

[2] NBSIR 74–467, Simulated Solar Heat Tests on MUST Air-Inflatable, Double-Wall Hospital Ward Shelters. Larry W. Masters, John W. Grimes, and Robert A. Crist, Center for Building Technology, National Bureau of Standards, Washington, DC. May 1974.

The cold temperature tests on the MUST inflatable shelters selected from current production are fully described in this report and Appendix A. The observations made during the conduct of the test, test results obtained, and the conclusions reached will complete this report.

BACKGROUND:

The Airesearch Division of the Garrett Corporation were the prime contractors to the Office of The Surgeon General for the development of the MUST shelter complex. The development of the inflatable units of the MUST complex was subcontracted to the Air Cruisers Division of the Garrett Corporation. Throughout the development of the inflatable shelters for the MUST complex dating back to 1963, a neoprene-Hypalon coated fabric was used, and the search for suitable adhesives for bonding this fabric was of prime concern. Many different adhesives were investigated. Two of the adhesives investigated were found to meet the rigid seam-load temperature requirements for the MUST inflatable shelters, a high temperature of 94°C (200°F) and a low temperature of −46°C (−50°F). The two adhesives are USM Chemical Company Bostik 1039 with Boscadur 5 accelerator (Bostik 1039/5) and USM Chemical Company Bostik 1095 with Boscadur 9 accelerator (Bostik 1095/9).[1] Air Cruisers built and delivered to The Surgeon General 1,420 MUST inflatable ward units. These were bonded with Bostik 1039/5 cement, and 105 inflatable MUST "Tee" corridor connectors were bonded with Bostik 1095/9 cement. All of the ward units and "Tee" connectors fabricated by Air Cruisers were successfully used in the field.

PRIOR LABORATORY TESTS

BONDING PROBLEM AND RELATED LABORATORY STUDIES:

The problem was to use an adhesive which would securely bond a Hypalon surface to a neoprene surface and a neoprene surface to a neoprene surface.

The US Army Medical Biomechanical Research Laboratory (USAMBRL), Washington, DC, studied the bond strength of Bostik 1095/5 when applied to Hypalon and neoprene. The cement was applied to abraded Hypalon and neoprene coated surfaces. Tests were run at room temperature, 20°C (68°F) and at high temperatures, 94°C (200°F). As a result of this study, it was found that to achieve maximum bond strength, the adhesive had to be diluted.[4] The adhesive formulation given in the report for which the highest bond strength, between Hypalon-neoprene and neoprene-neoprene surfaces, was observed is given as follows:

[3]Private communication from Mr. Earl Dix, Division Manager of Air Cruiser Company, a division of the Garrett Corporation, Belmar, NJ.

[4]Technical Report 6616: MUST Adhesive Bonding Evaluation. J. T. Heel, J. C. Eaton, and H. G. Mouhot, US Army Medical Biochemical Research Laboratory, Walter Reed Army Medical Center, Washington, DC 20012, October 1966.

Bostik 1095	32 parts by volume
Toluene	8 parts by volume
Boscadur 5	1 part by volume

EFFECT OF ABRADING SURFACES ON THE BOND STRENGTH BOSTIK 1039/5 AND BOSTIK 1095/9:

The Natick Research and Development Command (NARADCOM) conducted a study in 1974[5] of the adhesive bond strength of Hypalon to neoprene surfaces and neoprene to neoprene surfaces using both Bostik 1039/5/Toluene and Bostik 1095/9/Toluene adhesives. The comparative bond strengths of both adhesives were evaluated using unabraded and abraded specimens. The recommendations made by USAMBRL in their report using diluted adhesive (Bostik 1095/5) to achieve maximum bond strength between Hypalon to neoprene and neoprene to neoprene surfaces was accepted and followed in this test (reference 5). The test data from NARADCOM study showed that unabraded seams bonded with Bostik 1095/9, peeled at less than half the load required to peel specimens which were abraded. This was not the case with Bostik 1039/5 where the load required for the peel test was about the same for both unabraded and abraded specimens. It was concluded that the test data shows that the Bostik 1039/5/Toluene system can be successfully used in the MUST shelter, with or without abrading the Hypalon.

EFFECT OF TEMPERATURE ON THE ADHESIVE BOND STRENGTH OF BOSTIK 1039/5 AND BOSTIK 1095/9:

Another study conducted at NARADCOM in April 1974 (Appendix B) compared the relative bond strengths of the two adhesives, Bostik 1039/5 and Bostik 1095/9, at high temperatures, 94°C (200°F), and at low temperatures, −46°C (−50°F). Based on the results of this test the following observations were made:

a. The performance of the adhesive Bostik 1095/9 at elevated temperatures (94°C) is a little less than that of Bostik 1039/5, but its suitability in this respect is not questioned in view of the good results obtained in the National Bureau of Standards simulated solar load tests of the shelter sections.[6] As a result of this test it was found that both adhesives withstood high skin temperatures (94°C) equally well.

[5] Clothing & Personal Life Support Equipment Laboratory, Chemical Products Research and Engineering Division, Chemicals, Leather and Paper Engineering Branch Report, Project number 40342102, Evaluation of Cemented Seams Proposed for the Shelter Inflatable (MUST), Carl Frenning, dated 1 May 1974 (Appendix B).

[6] NBSIR 74–467, Simulated Solar Heat Tests on MUST Air-Inflatable, Double-Wall Hospital Ward Shelters. Larry W. Masters, John W. Grimes, and Robert A. Crist, Center for Building Technology, National Bureau of Standards, Washington, DC, May 1974.

b. The adhesive Bostik 1095/9, in film form at low temperatures is appreciably stiffer than an equal film made from Bostik 1039/5. It was concluded that these results cannot be translated into effects on shelters in the field. It is believed that the cracking of the adhesive film observed during the laboratory tests would not occur in the field since folds as sharp as the rolled folds in the laboratory test will probably not occur in the field. However, the increased stiffness may affect the cubage of the packad shelter, even though the adhesive covers only five percent of the total coated fabric surface. It was recommended in this laboratory report that the shelters coming off the production lines using Bostik 1095/9 adhesive be subjected to low temperature unpacking, inflation and repacking, in comparison with corresponding shelters made with Bostik 1039/5 adhesive.

PRIOR FIELD TESTS

THE EGLIN AIR FORCE BASE TEST:[7]

A MUST Hospital Systems* test was conducted under controlled ambient temperatures at the Eglin Air Force Base, Florida, 13 October through 16 November 1968. One phase of this test consisted of erecting and repacking the inflatable ward shelter at −40°C (−40°F) ambient temperature. The test team found: "By rolling the inflatable shelter twice during repacking, a normal bundle size was achieved. Due to material stiffness encountered at −40°C, it takes about twice as long for the air to escape. The rolling operation did not deteriorate the material in any manner."

The test at Eglin Air Force Base included the inflatable ward shelter and the "T" corridor connector. During the test one unit experienced a casing rupture at low temperature. The test team did not consider this a serious deficiency. It may be concluded from this controlled ambient temperature test that the MUST shelter complex is operational at temperatures as low as −54°C (−65°F). It is significant to note at this low temperature, both the inflatable ward shelter fabricated with Bostik 1039/5 and the inflatable "Tee" corridor connector fabricated with Bostik 1095/9 were operational at −54°C in the controlled ambient temperature test.[8]

[7] System Test on MUST Hospital under Controlled Ambient Temperatures at Eglin Air Force Base, Florida, 13 October through 16 November 1968.

*The MUST inflatable ward units and "Tee" corridor connectors in this test were manufactured by the Air Cruisers Division of the Garrett Corporation.

[8] System Test on MUST Hospital under controlled ambient temperatures at Eglin Air Force Base, Florida, 13 October through 16 November 1968.

FIELD MEDICAL EVALUATION, MAJOR MUST EQUIPMENT IN ALASKA:[9]

A cold weather evaluation was made of the major MUST equipment at Fort Wainwright, Alaska, from 8 January through 1 February 1973. The maximum and minimum ambient temperatures recorded by the ASL Alaska MET Team at Fort Wainwright for the test period are shown in Table 1. The temperatures shown on Table 1 should be taken as indicative of the area temperatures only and not those at the test site. The ambient temperatures at the test site were not given in the report and may be higher or lower than the area temperature recorded by the MET team.

The test in Alaska included the four inflatable ward shelters but not the inflatable "Tee" corridor connectors. Among the observations reported by the test team, two were directly related in part to the material property of the coated fabric stiffening at cold temperature. One observation was that the inflation of a four-section inflatable ward shelter required 75 minutes at −49°C (−56°F) compared to the 17 minutes required in a more temperate climate. The other observation was that an inflatable section which can normally be rolled into a bundle 180 cm (6 feet) by 90 cm (3 feet) cannot be rolled into a bundle smaller than 390 cm (13 feet) by 90 cm (3 feet).

At the end of the cold weather test in Alaska it was concluded that "A MUST Hospital can be operated in an arctic winter environment of extremely low humidity and provides a facility far superior to any presently available for arctic operation."

Report of NARADCOM Representative to Alaska Test:

A representative from NARADCOM was sent to Alaska, to observe the MUST cold weather test.[10] He reported that the shelter was struck at a temperature of −42°C (−45°F). Six men were able to fold and pack each section so that it was possible to place them in a ward container. The bulk of each section was 1/2 to 2/3 larger than the original pack.

It is important to note that the MUST inflatable shelters built by the Air Cruiser Division of the Garrett Corporation were functional in the cold weather test both at the Eglin Air Force Base and the field test in Alaska. The increased bulk of the "rolled up" shelters reported in both tests is a consequence of the material properties — the coated fabric stiffens at low temperatures. This is an important factor to consider under

[9] Report of Field Medical Evaluation Major MUST Equipment in Alaska, US Army Medical Material Agency, Medical Equipment Test and Evaluation Division, Fort Sam Houston, Texas 78234, Fort Wainwright, Alaska, test 8 January through 1 February 1973, reported dated 30 March 1973.

[10] Report of Travel of Frank O. Johnson, L. O. 12 dated 4 January 1973, to Fort Wainwright and Fort Greeley, Alaska, 21 through 27 January 1973.

TABLE 1

Temperatures Reported by the ASL Alaska MET Team, Fort Wainwright Detachment for the Cold Weather Test of Major MUST Equipment in Alaska in Degrees Fahrenheit

	DATE (1973)	MAXIMUM	MINIMUM
January	8	+19	+ 2
	9	+ 9	− 6
	10	+12	+ 9
	11	+ 9	−25
	12	−21	−42
	13	−41	−47
	14	−44	−48
	15	−46	−49
	16	−48	−53
	17	−49	−56
	18	−36	−50
	19	−40	−48
	20	−39	−49
	21	−43	−49
	22	−36	−49
	23	−37	−48
	24	−38	−50
	25	−46	−53
	26	−35	−49
	27	0	−44
	28	+28	−13
	29	+29	− 3
	30	− 3	−13
	31	−11	−34
	1	− 4	−38

field conditions where space is at a premium such as in a ward container. One way of ameliorating this problem would be to roll the shelter twice as reported for the test conducted at the Eglin Air Force Base.[11]

NARADCOM COLD TEMPERATURE TEST

BACKGROUND SUMMARY AND OBJECTIVE:

The cold temperature test projected for the MUST inflatable units, to be conducted in the NARADCOM Sir Hubert Wilkens Arctic Chambers, is based on the following considerations:

a. The search for a suitable adhesive for the MUST inflatable shelters started before 1963 and is still continuing. This adhesive must form an effective bond between Hypalon-to-neoprene and neoprene-to-neoprene surfaces and hold over wide temperatures extremes, a low of −46°C (−50°F) and a high of 94°C (200°F). To date, the two adhesives which were found to meet the severe bonding requirements listed above are as follows:

(1) Bostik 1039/5

(2) Bostik 1095/9

b. The tests conducted by the Office of The Surgeon General on the MUST inflatable shelters suggests that either Bostik 1039/5 or Bostik 1095/9 can be successfully used to fabricate functional inflatable field shelters which are operational under extreme hot and cold temperature conditions.

c. Laboratory tests at NARADCOM (Appendix B) recommended that shelters coming off the production line using Bostik 1095/9 adhesive be subjected to high and low temperature tests in comparison with corresponding shelters made with 1039/5 adhesive. The critical parameter for high temperature test is the delamination of cemented seams and strapping. The critical parameter for low temperature tests is the relative seam stiffness and its effect on the packaged cube of the shelter.

d. A simulated solar load test on MUST air inflatable, double wall, hospital shelters was conducted by the National Bureau of Standards (NBS), Washington, DC, on shelters fabricated with the two adhesives. In general, the results of the NBS test on the shelter

[11] System Test on MUST Hospital under Controlled Ambient Temperatures at Eglin Air Force Base, Florida, 13 October through 16 November 1968.

sections were favorable for both adhesives. The conduct of the test as well as the results obtained is the subject of a separate report[12] and need not be repeated in this study.

e. No studies could be found which compared the relative cold temperature performance of the two adhesives and their effects on the seam stiffness and package cube of shelters in the field. The objective of this study is the two adhesives and their effect on the shelters in which they are used.

CONTROLLED COLD AMBIENT TEMPERATURE TEST FOR MUST UNITS:

A controlled cold ambient temperature test on air-inflatable MUST shelters was implemented at NARADCOM using the Sir Hubert Wilkens Arctic Chambers to generate the controlled cold ambient temperature required for cold soaking the shelters. The overall test plan is covered in Appendix A of this report. From the test plan it can be seen that the two quantifiable objectives to be achieved in this study are as follows:

a. Determine the effect of cold temperature on the relative seam stiffness of shelters fabricated with each of the two adhesives, Bostik 1039/5 adhesive and Bostik 1095/9 adhesive.

b. Determine the relative package cube of shelters fabricated with each of the two adhesives.

Description of the Shelters:

Each air-inflatable, double-wall hospital shelter section which was evaluated consisted of either 12 or 13 individual semi-cylindrical chambers approximately 0.5 m (20 in) in diameter and 10.7 m (35 ft) in length. The dimension of the erected shelter section measured approximately 7.3 cm (24 feet) in width, 4.3 m (14 feet) in length, and 3.7 m (12 feet) in height. Figure 1 is a picture of one of the erected shelter sections. The sections are designed to be joined together to form a shelter of the desired length.

The shelter sections are constructed with an exterior skin consisting of a polyester fabric coated on the back side with black neoprene and on the face side with black neoprene, olive green chloroprene (neoprene)*, and olive green chlorosulphonated polyetylene (Hypalon)*. The interior skin of the shelter sections consists of a polyester fabric coated on the face side only with black neoprene, pale green neoprene, and pale

[12] NBSIR 74–467 Simulated Solar Heat Tests on MUST Air-Inflatable, Double-Wall Hospital Ward Shelters. Larry W. Masters, John W. Grimes, and Robert A. Crist, Center for Building Technology, National Bureau of Standards, Washington, DC, May 1974.

*Products from E. I. duPont de Nemours, Wilmington, Delaware

FIG. I M.U.S.T CORRIDOR CONNECTOR IN THE COLD TEMPERATURE CHAMBER AT NLABS

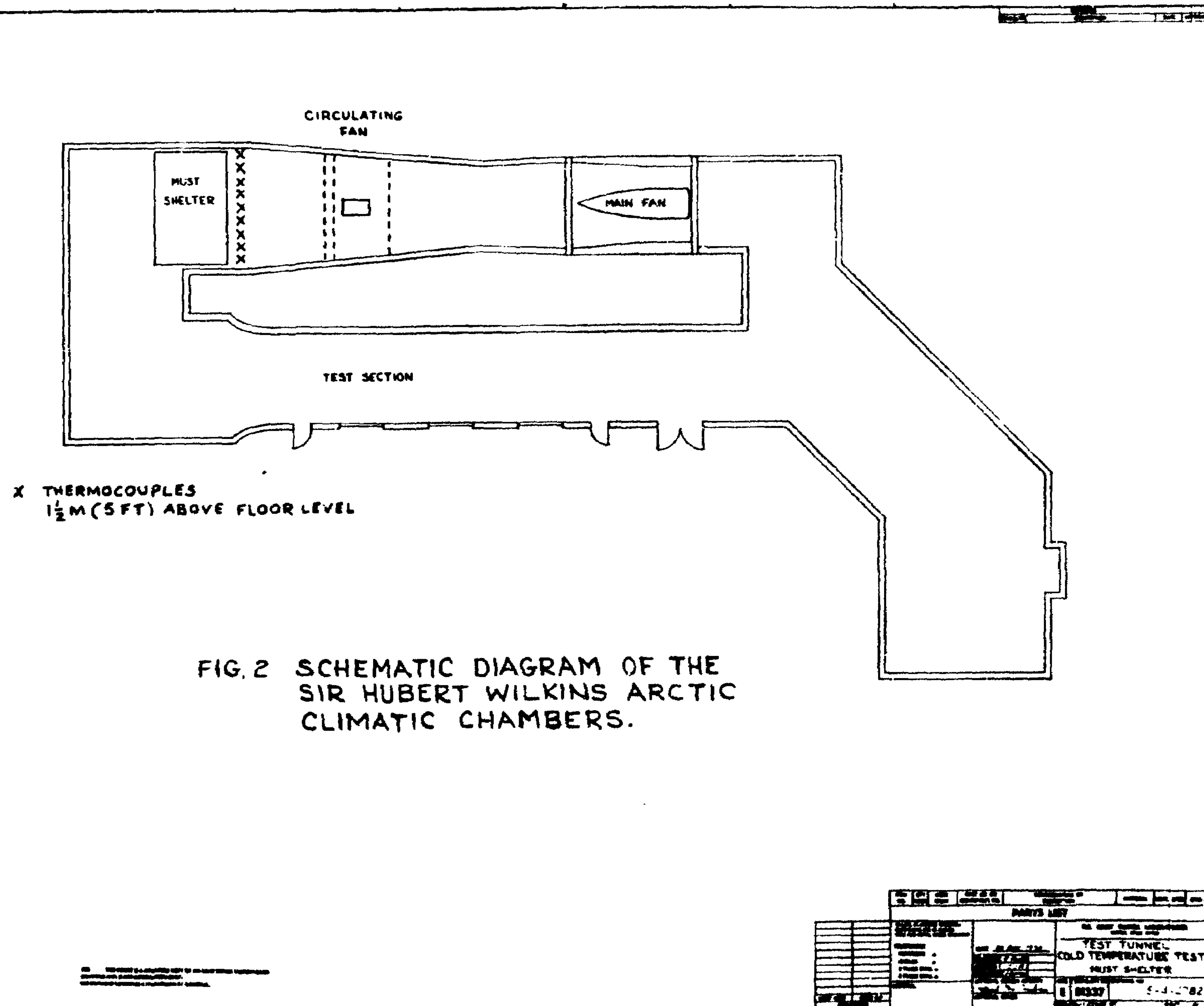

FIG. 2 SCHEMATIC DIAGRAM OF THE SIR HUBERT WILKINS ARCTIC CLIMATIC CHAMBERS.

green Hypalon. The result of this is that the entire exposed exterior surface was olive green Hypalon and the entire exposed interior surface was pale green Hypalon.

The exterior and interior skins are joined by coated cloth webs which are sewn to each skin, thus forming the individual semi-cylindrical chambers. The cloth webs were fabricated from polyester cloth coated on one side with neoprene. An air-inflatable bladder, placed inside each semi-cylindrical chamber, is fabricated from nylon cloth coated on one side with neoprene.

Each semi-cylindrical chamber and bladder is equipped with an air inlet valve, an air pressure release valve and a check valve. The air pressure release valve is designed to prevent over-pressurization and the check valve allows each cell to remain inflated regardless of what happens to the other cells in the section. When the shelter is erected, each bladder is designed to contain an air pressure of 10.247 kPa (1.5 psi).

Test Shelter Specimens:

The three shelter sections which were tested were obtained from three diffferent sources, as follows: Atlanta Army Depot, Forest Park, GA; Tobyhanna Army Depot, Tobyhanna, PA; and from the National Bureau of Standards, Washington, DC. Two of the sections are corridor connectors fabricated by the Inflated Products Company, and the third shelter was a hospital ward section fabricated by Firestone. The shelter sections will be designed as 1A, 2T and 3N. The serial numbers of the tested shelter sections are as follows:

Shelter Section Number	Serial Number
1A	---
2T	125
3N	S 057

Shelter sections 1A and 2T are corridor connectors which were constructed according to NARADCOM Limited Production Purchase Description LP/P DES 39-70 (26 August 70) except for authorized changes. The corridor connector shelter sections contain a doorway on each side of the section as shown in Figure 1. Section 3N is a shelter section and was constructed according to Limited Production Purchase Description LP/P DES 42-70 (1 September 1970) except for changes approved by NARADCOM.

Test Apparatus and Procedure:

The arctic climatic chamber at Natick was used to induce the controlled low temprature required to cold condition the shelter sections and maintain the low temperatures needed to perform the necessary tests. Figure 2 is a schematic diagram of the arctic climatic chamber showing the location of a shelter section throughout the test period. The arctic climatic chamber is a closed circuit wind tunnel in which the temperature can be lowered, controlled, and maintained at any level down to −54°C (−65°F). The shelter section was too large to fit in the test section of the tunnel. The shelter had to be erected in the plenum chamber, directly behind the circulating fan and in front of the turning vanes. A low wind speed of 1.38 m/s (3.1 miles/hour) was maintained to insure a uniform temperature in all sections of the test chamber. The interior temperature of the test chamber was monitored by the chamber's own internal control and temperature indicating devices. In addition, an independent system of ten thermocouples was strung across the test chamber on the windward side of the shelter 1.5 m (5 feet) above the floor. The chamber temperatures recorded in this test were those registered by the ten thermocouples.

A test team of 12 men of different skills, suitably outfitted with arctic clothing, are required to conduct the cold temperature test on the shelter section. The team is made up of the following personnel: a minimum of six enlisted military personnel to roll and/or fold the shelter for storage; one engineer to keep the inflation unit operational at the low test temperatures and keep the shelter inflated; two equipment (MUST inflated shelter) specialists; one test coordinator; one coated fabric specialist; and one adhesive specialist. Figure 3 shows eight of the twelve-man test team in full arctic clothing after completing a test run at −40°C (−40°F).

Following is the sequence of operations observed in the conduct of the test. The shelter section is placed in its proper location in the test chamber at ambient temperature and inflated. The shelter section is then examined to establish its condition at the start of the test. All defects found are noted and recorded. The temperature in the chamber is then lowered and held at the desired level. The shelter section is allowed to cold-soak for one to two days.

On the day when tests are to be performed the shelter is fully inflated and planned to cold-soak for a minimum of two hours before conducting the tests. After the shelter is properly cold-conditioned, it is examined. Any deficiency which may have resulted from exposure to the low temperature is recorded. The air exhaust ports on the inlet valves are then opened to deflate the shelter section.

Fig. 3 Eight of the Twelve-Man Test Team in Arctic Clothing

The instructions for deflating the shelter given in the Operator's Mannual[13] are as follows:

a. Deflate the shelter section by setting the inflation check valve in the deflate position.

b. As the shelter is deflating, six or more men guide the shelter so that it will lie flat when all the air is exhausted, without covering the manifold.

The shelter takes considerable time to deflate at room temperature, and even then it is almost impossible to remove all residual air without manually forcing it out. The removal of as much residual air as possible is necessary to minimize the storage space requirement for the shelter section which is at a premium in the MUST shelter system. The six-man test team did manually force the residual air out of the shelter by various means such as crawling over the shelter on hands and knees, lying and rolling on the shelter, and even walking on the tubes of the shelter to force enough air out to achieve the smallest possible storage area for the shelter. The shelter is then arranged as flat as possible on the floor. The test team is now ready to measure the relative seam stiffness induced by the low temperature in the arctic chamber.

Relative Seam Stiffness Test:

The apparatus required to evaluate the relative seam stiffness of coated fabrics is shown in Figure 4. It consists of the following items:

a. A baseboard: 0.6 m (2 ft) x 0.6 m (2 ft) x 0.02 m (3/4 in).

b. Three weights: 0.97 kg (2.14 lb), 2.3 kg (5 lb), and 4.5 kg (10 lb).

c. A tubular weight guide to position the weight on the loop of the seam.

d. A stand to hold the guide.

e. A steel rule, 0.3 m (1 ft) long, 1.6 mm (1/16 in) divisions. All of the equipment used to evaluate the relative seam stiffness of the shelter was temperature-stabilized before use.

To perform the relative seam stiffness test, a portion of the shelter, containing the seam to be measured, was made as smooth as practical. An uncompressed S-shaped fold

[13]Department of the Army Technical Manual TM-10-5410-222-10 inflatable shelters w/airlock (Airesearch Manufacturing Co. Model SIW-1) FSN, operators manual 5410-933-9388, 1969.

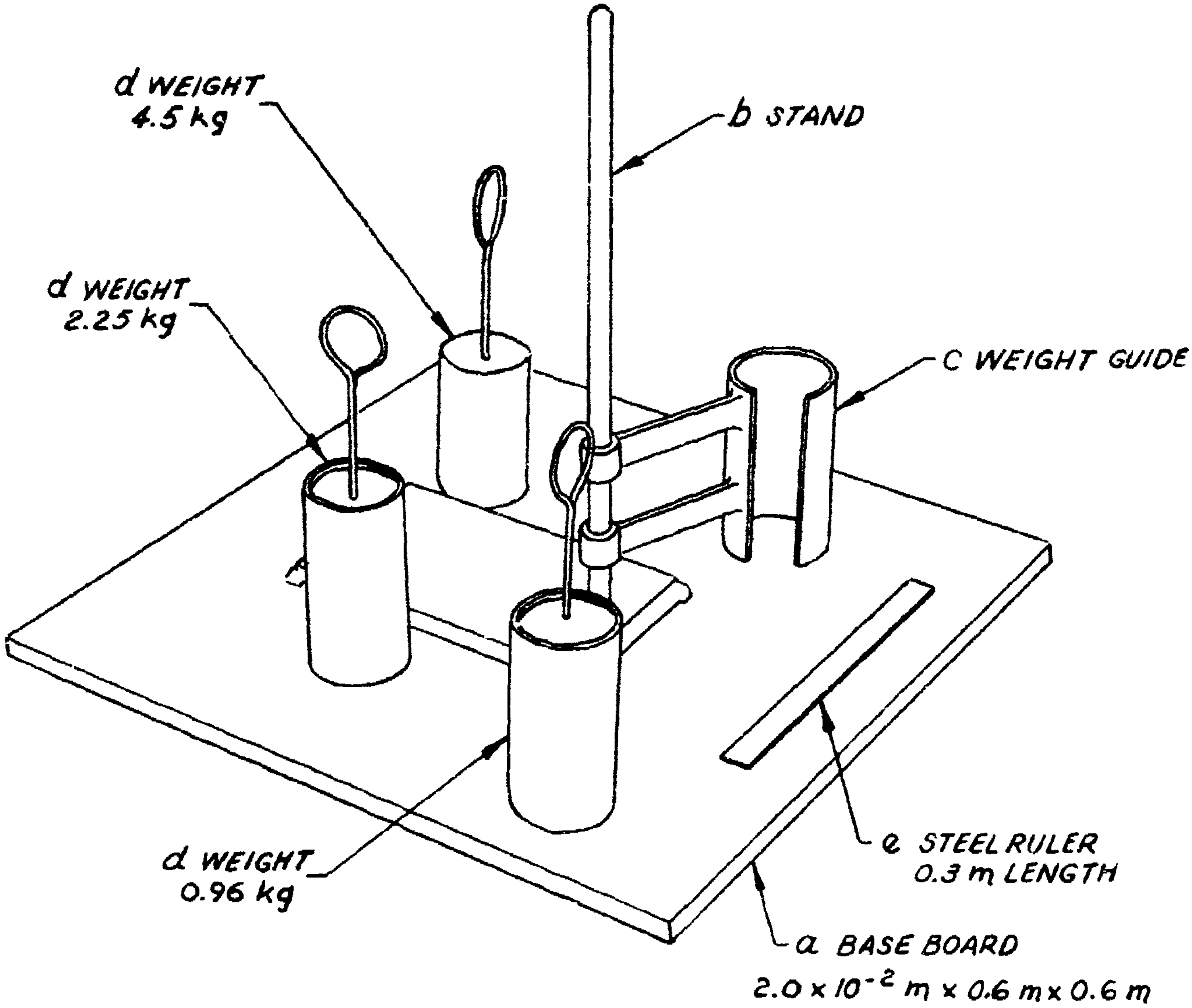

FIG.4 APPARATUS FOR EVALUATING THE RELATIVE SEAM STIFFNESS OF M.U.S.T SHELTER SECTION

(a double loop) was made about 0.25 m (10 in) to 0.30 m (12 in) long measured in a horizontal direction parallel to the seam. The outer edges of both loops in the S-shaped fold were approximately perpendicular to the seam. The centerline of the three seam sections in the S-shaped fold were approximately in the same vertical plane. The base board (Item a in Figure 4) was placed in the S-shaped fold under the top loop, inside of the bottom loop, and on top of the bottom layer of fabric. The base board was adjusted under the top loop until the top fold of the fabric covered an area 0.6 m (24 in) long by 0.25 m (10 in) wide, or 0.15 m^2 (240.0 in^2). The seam to be measured was approximately in the center of the fold in the fabric. The stand (Item b in Figure 4) was placed on a bare part of the base board and the weight guide (Item c in Figure 4) positioned over the loop in the seam. The 0.076 m (3.0 in) diameter, 0.152 m (6.0 in) long cylindrical weight, 0.96 kg (2.14 lb) (Figure 4 shows the three weights to be approximately the same dimensions) is placed in the weight guide and carefully lowered onto the loop in the seam. As the weight was being lowered, the weight guide was adjusted to fulfill the following conditions:

a. The loop in the seam would support the entire downward force of the weight.

b. The bottom edge of the weight would project from the bottom of the tube. The shortest distance from the bottom edge of the weight, at the place it projected outward from the loop in the seams, to the top surface of the base board was measured with a steel rule. The distance was the loop height of the seam under 0.97 kg (2.14 lb) compressive load and was used as a measure of the relative seam stiffness under this load. The procedure of placing the weight on the loop of the seam and measuring the loop height was repeated replacing the 0.97 kg weight with a 2.3 kg (5 lb) weight and repeated again with a 4.5 kg (10 lb) weight. A new seam loop was formed using the same seam but a different location. The whole test was repeated, measuring the seam height obtained with each of the three different weights.

Measurement of Storage Volume of the Shelter Section:

The measurement of the storage volume of the shelter section requires two separate operations as follows:

a. Rolling up the shelter section preparatory to measuring its package volume.

After the measurements for relative seam stiffness were made and prior to rolling up the shelter, the shelter is examined and, if necessary, the test team would force more air out of the inflatable tubes in the shelter section. This was accomplished by the test team rolling from one end of the tubes to the other and sometimes by walking on them. The team would start at the end of the shelter opposite the manifold and work the air out toward the manifold. Just before starting to roll up the collapsed shelter, the test team would straighten it out so that it lay completely unfolded and as flat on the floor as the team could reasonably be expected to make it lie. The test team, six or more men, would line up on the side opposite the manifold and start rolling up the shelter section. Generally, the team would start by making a narrow fold along the outer edge of the shelter along its entire length. The team would press the residual air out of the shelter section as they rolled it up, making the narrow fold the core of the roll. The

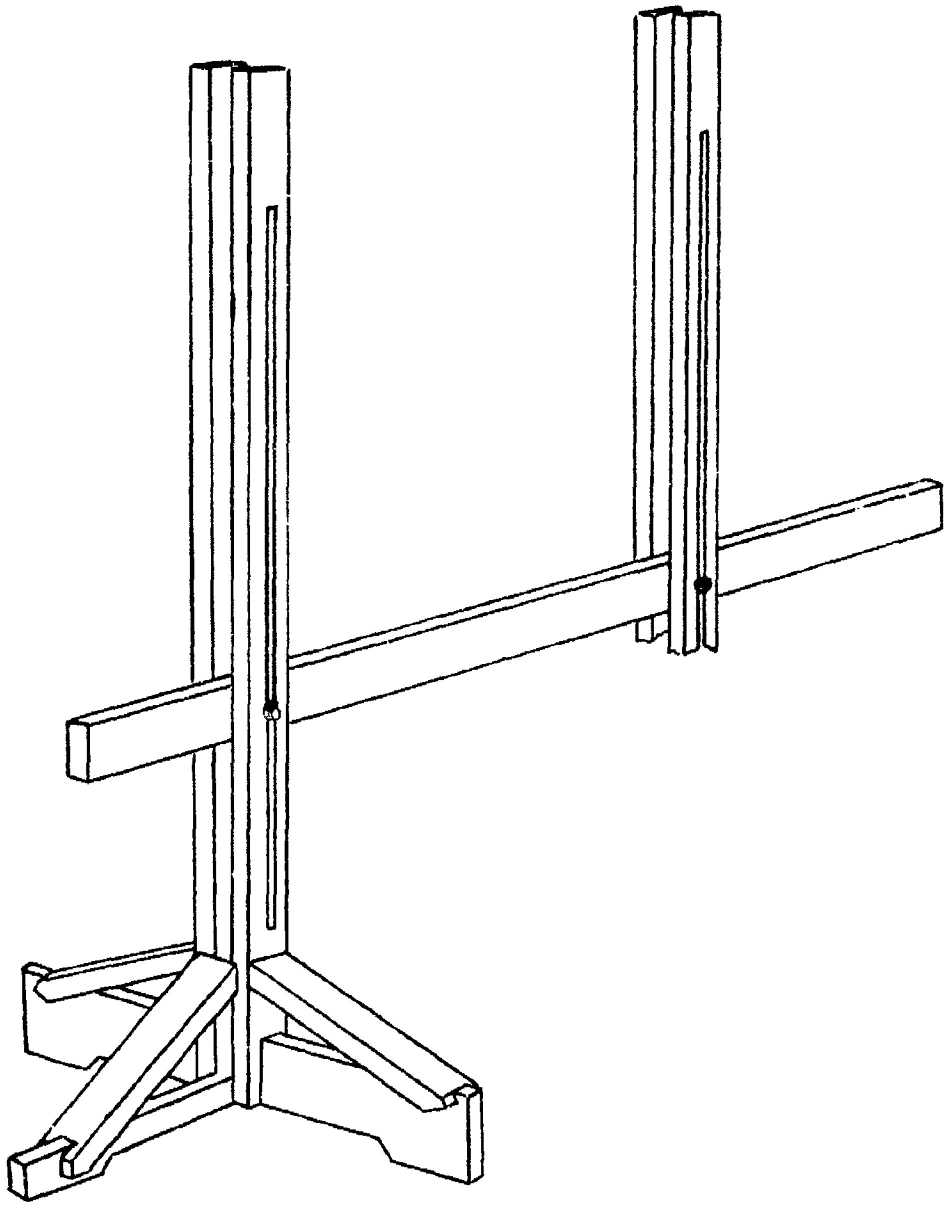

FIG. 5 THE RACK FOR OBTAINING THE MEASURMENTS NECESSARY TO CALCULATE THE RELATIVE STORAGE VOLUME OF THE SHELTER SECTIONS

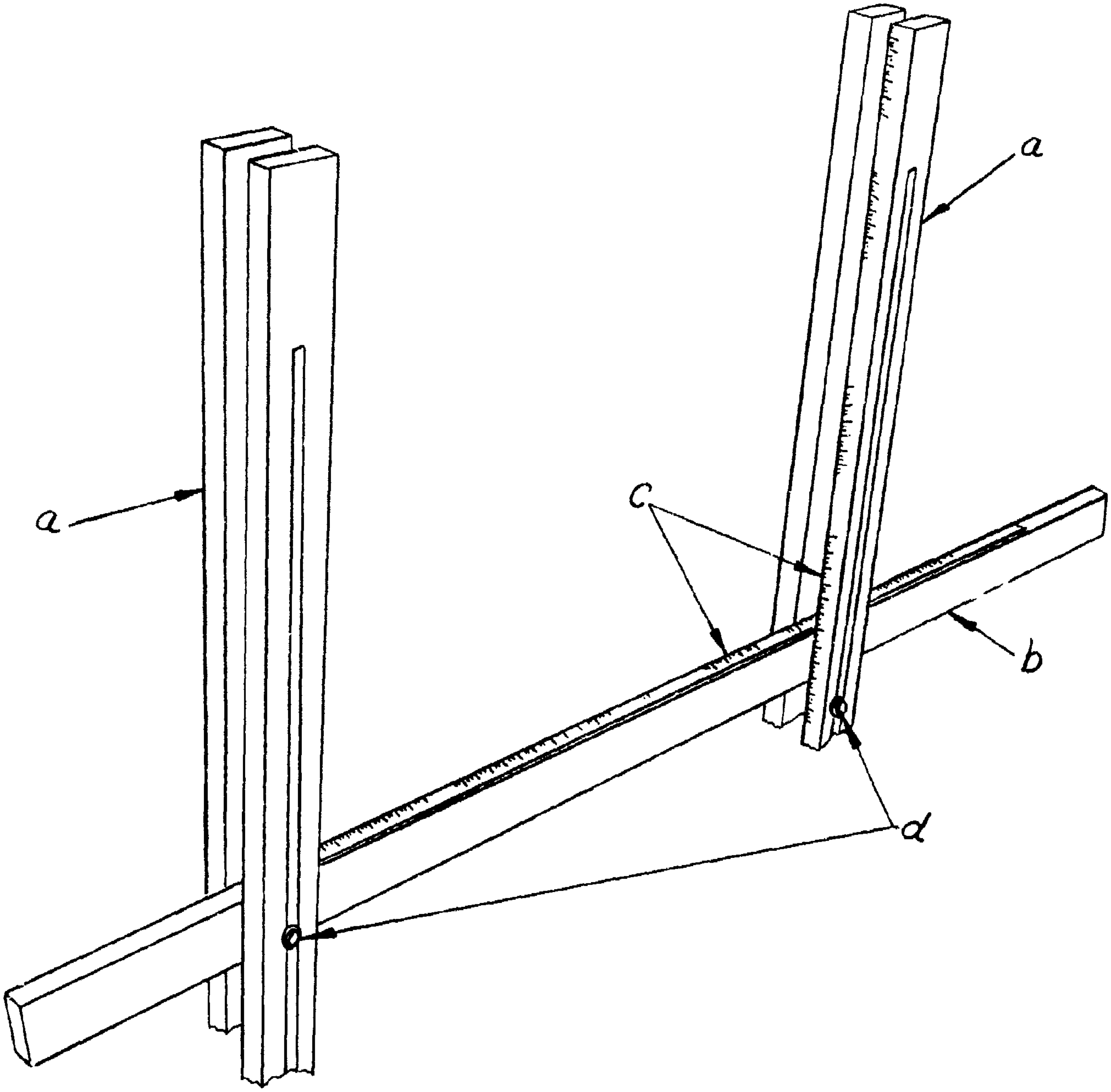

FIG. 6 SHOWING METER STICKS (c) FASTENED TO UPRIGHT (a) AND CROSS MEMBERS (b) OF THE RACK, ALSO THE BOLT FASTENER (d) TO HOLD THE CROSS MEMBER IN PLACE WHILE MEASUREMENTS WERE TAKEN.

team would usually stop rolling up the shelter as they approached the manifold end. They would then fold the manifold end back on itself and lay the fold on the top of the roll. The amount of air forced out of the shelter section during the roll-up operation depended on the speed and care used as well as the number of men used to roll up the shelter.

b. Measuring the storage volume of the rolled up shelter section.

A measuring rack was constructed to measure the height and width of the rolled up shelter (Figures 5 and 6). The rack consisted of two upright members (Item a in Figure 6). The two members are slotted from the top to within 0.25 m (10.0 in) of the floor. A cross member, about 2.1 m (7.0 ft) long, was cut. The cross member (Item b in Figure 6) was selected to fit the slot in each stand. The inside of the two upright members, the floor and the bottom of the cross member formed a figure with four straight sides with 2 or 4 right angles. Each of the upright members and the cross member were fitted with meter sticks (Item c in Figure 6) for ease of measuring. Also, provisions were made for tightening each slot on the upright members (Item d in Figure 6) to hold the four-sided figure in the selected position while the measurements were taken.

The measurements required to calculate the cross-sectional area of the roll are taken at three places along the length of the roll, approximately 0.46 m (18.00 in) from each end of the roll and in the center. To obtain these measurements, the upright members of the rack are jammed tightly at both sides of the shelter roll and the cross member jammed tightly on top of the roll and locked in place. These forces, plus the weight of the roll against the floor, tended to force the cross-sectional area of the shelter roll being measured into a straight four-sided figure with either two or four right angles. The area of this four-sided figure minus the area of any voids noted within the area is determined. The area determined is taken as the cross-sectional area of the shelter minus the area of the voids. The length of the shelter is measured with a flexible steel tape. The storage volume of the shelter section is calculated using the cross-sectional area times length of the shelter section roll obtained as noted above.

TEST CONDITIONS AND OBSERVATIONS

TEST CONDITIONS:

The Sir Hubert Wilkens Arctic Test Chamber was used to generate the cold temperature test conditions required for this test. Figure 1 shows a MUST corridor connector installed in the plenum chamber of the test tunnel. In accordance with the test plan (Appendix A), the shelter sections were tested under the following cold temperature conditions: 21°C (70°F), −18°C (0°F), −29°F (−20°F), −40°C (−40°F) and −46°C (−50°F) ambient. Following dicussions with the engineers operating the climatic chambers, the daily test schedule given in Table 2 was agreed upon for the two MUST corridor connectors.

TABLE 2

Daily Test Schedule for the Two MUST Corridor Connectors in the Climatic Chambers

DATE	DAY	ACTIVITY
15 Apr	Mon	Set up Shelter Number 1 (1039/5 adhesive). Observe and test at 21°C (70°F) ambient.
16 Apr	Tue	Reduce temperature to −18°C (0°F) and maintain.
17 Apr	Wed	Maintain at −18°C, observe and test at 1000 hours and at 1330 hours.
18 Apr	Thu	Reduce temperature to −29°C (−20°F) and maintain.
19 Apr	Fri	Maintain at −29°C, observe and test at 1000 hours and at 1330 hours.
22 Apr	Mon	Reduce temperature to −40°C (−40°F) and maintain.
23 Apr	Tue	Maintain at −40°C, observe and test at 1000 hours and at 1330 hours.
24 Apr	Wed	Reduce temperature to −46°C (−50°F) and maintain.
25 Apr	Thu	Maintain at −46°C, observe and test at 1000 hours and at 1330 hours.
26 Apr	Fri	Allow test chamber temperature to rise slowly to 21°C (70°F) ambient.
29 Apr	Mon	Remove Shelter Number 1; install Shelter Number 2 (1095/9 adhesive); observe and test Shelter Number 2.
30 Apr	Tue	Observe the same daily testing program, temperature, time; observe and test sequence given above for Shelter Number 1 from Tue 30 Apr through Fri 10 May.
13 May	Mon	Observe and test Shelter Number 2; remove shelter and all other test equipment from the chamber; this test phase is completed.

In the above test, except for Shelter Number 1 which was tested only once at −18°C (0°F) at 1330 hours, all other tests for relative seam stiffness and storage volume of the MUST corridor connector were conducted twice for each test temperature, once at approximately 1000 hours and the second time at approximately 1330 hours. This means that Shelter Number 1 was inflated, deflated, rolled and walked on, tested for relative seam stiffness, rolled up to determine its storage volume, unrolled and reinflated nine times during the two-week test period. Shelter Number 2 was subjected to the same handling procedure ten times over the same period of time. The two shelters were subjected to a more severe handling in this test than they would receive under normal field operations; see Operator's Manual.[14]

OBSERVATIONS:

Shelter Section Number 1A (Bostik 1039/5 adhesive).

The actual temperature of the test chamber, time and duration of the testing cycle and the cold soak period at the designated temperature for this shelter was as given on Table 3.

It can be seen from Table 3 that one test run was made with no cold soak at the designated temperature of −40°C, and another run was made with less than the two hours cold soak at −29°C.

The shelter section number 1A, received from Atlanta, GA, has been exposed to the environment, as indicated by the discoloration of the excess cement along the edges of the cemented seams. The shelter was examined prior to testing and the following deficiencies noted:

a. The strapping showed many areas of delamination estimated at 15% to 20% of the total strapped area.

b. Cell number 13 was badly torn, as shown in Figure 7.

c. Some separation of the outer shell was observed in cells numbers 1, 2, 5, 6, 9 and 10.

[14] Department of the Army Manual TM 10–5410–222–10, Inflatable Shelters w/Airlock (Airesearch Manufacturing Co. Model SIW–2) FSN, Operator's Manual 5410–033–9388, 1969.

TABLE 3

The Actual Temperature of the Test Chamber and Time and Duration of the Testing Cycle and the Cold Soak Period for the Shelter Section Number 1A

Temp* (°C)	Time Attained Hours	Start Test Hours	Cold Soak Hours**	Comp Test Hours	Comments
21	0645	1400	7.75	1515	Ambient room temperature
–18	0830	1030	2.00	1140	2-hour cold soak
–18	0830	1400	5.50	1310	———
–29	0910	1030	1.33	1120	Less than 2 hours cold soak
–29	0910	1400	4.83	1510	———
–40	1030	1030	0.00	1130	No cold soak
–40	1030	1400	3.50	1515	———
–46	0730	1030	3.00	1135	———
–46	0730	1400	5.50	1505	———

*Temperature registered by the ten thermocouples mounted in the tunnel on the windward side of the shelter.

**Duration of cold soak at designated temperature.

FIG. 7 - DAMAGE DUE TO PRIOR USE ON SHELTER IA BEFORE TESTING (BOSTIK 1039/5)

The cementing on the shelter and general construction was not good. However, the shelter had to be used for the test because it was the only corridor connector available and known, with reasonable certainty, to be fabricated with Bostik 1039/5 adhesive. In addition, it would remain inflated and erect at ambient room temperatures for several hours.

At 21°C (70°F): As expected, the deflation and handling of the shelter was no different than at ambient room temperature. There was no apparent additional damage to the shelter as a result of handling in this test. The relative seam stiffness and storage volume were about the same as at room temperature. The shelter was easily reinflated.

At −18°C (0°F): The shelter did not remain fully inflated overnight. The full blower pressure in the shelter was restored shortly after 0800 hours. The shelter was easily deflated and rolled up without undue difficulty. The package volume did not increase much at this temperature. There appeared to be no increase in discernible damage to the shelter and it reinflated easily.

At −29°C (−20°F): The shelter remained as before; there appeared to be no extra damage; the folding was not too difficult; and the package volume did not increase very much. The fabric showed a slight stiffness and produced a paper crinkle sound when folded. The shelter required a somewhat longer time to reinflate than that required at room temperature (21°C).

At −40°C (−40°F): The shelter was down before testing. The cloth was stiff but still able to be handled. The package volume and the relative seam stiffness increased. The shelter was reinflated for the afternoon test. The shelter remined inflated for only one and one-half hours. It was observed that air was leaking through the manual check valve. To gain some insight on whether the valve's diaphragm may be faulty, two diaphragms were placed in the chamber, one diaphragm was taken from an old shelter, not in current production and the second from one of the new shelters. After 4 hours at −40°C both diaphragms retained complete flexibility, the only difference noted was that the newer diaphragm seemed to be a little slower in recovering its flat condition after it was bent over on itself at this low temperature. The shelter was appreciable stiffer in the afternoon than in the morning test. Due to a longer cold soaking time at the test temperature of −40°C (Table 3) the shelter was more difficult to handle; the relative seam stiffness and storage volume increase.

At −46°C (−50°F): The shelter was down in the morning and could not be reinflated prior to testing. The material was extremely stiff and the noise was sharper and louder when the fabric was depressed or bent. The relative seam stiffness and package volume increased again. Peeling of the coating on the outer shell was observed. See Figure 8. There is a high probability that peeling of the coating may have occurred on the seams

FIG.8 PEELING OF THE COATING ON THE OUTER SHELL INCLUDING SOME SEPARATION OF THE STRAPPING

and the coating of the bladders. The bladder and shell material will be examined at the conclusion of this test to discover the reasons for the failure of the shelter to inflate. The details of the examination of the bladder and shell material are beyond the scope of this report but will be reported separately. There were few or no changes in the relative seam stiffness and storage volume of the shelter in the afternoon test relative to those found in the morning test at −46°C (−50°F).

At 21°C (/0°F): The relative seam stiffness and storage volume were found to be approximately the same as those found at the start of the test. The shelter section could not be reinflated to its original configuration.

Shelter Section Number 2T (Bostik 1095/9 Adhesive):

The actural temperature of the test chamber, time and duration of the testing cycle and the cold soak period at the designated temperature for this shelter was as shown on Table 4.

It can be seen from Table 4 that there were three test runs when the shelter was not cold-soaked for a full two hours at the designated temperature, namely at −18°C, −40°C and −46°C.

Figure 9 shows the identification of shelter section number 2T, the air duct manifold and four intake check valves. The handles, shown on the check manual valve, are turned to open the pork hole and vent the bladder to the atmosphere to deflate the shelter.

At 21°C (70°F): The bladders in this shelter contain one additional ounce of coating than previously specified. The appearance of the erected shelter was generally good and a marked improvement over the shelter section number 1A already tested. There were no observable delaminated areas.

In this morning test the shelter was deflated and tested for relative seam stiffness and storage volume. The coated fabric was soft and did not make much noise when folded or bent. The shelter was easy to handle and no difficulty was experienced in rolling up the shelter or reinflating it. The shelter was inflated in less than ten minutes.

The test results and observations made in the afternoon were about the same as those obtained in the morning.

At −18°C (0°F): The shelter was deflated and tested for relative seam stiffness and package volume. The coated fabric was relatively soft and did not make much noise when handled. The shelter handled easily and no difficulty was experienced in rolling it up. The package volume appeared to show a slight increase. The shell did not show

TABLE 4

The Actual Temperature of the Test Chamber, Time and Duration of the Testing Cycle and the Cold Soak Period for the Shelter Section Number 2T

Test Temp* (°)	Time Attained Hours	Start Test Hours	Cold Soak Hours**	Comp Test Hours	Comments
21	0645	1030	3.75	1130	Ambient room temperature
21	0645	1400	7.25	1515	------
−18	0945	1045	1.00	1150	Less than 2 hours cold soak
−18	0945	1400	4.25	1515	------
−29	0750	1030	2.67	1135	------
−29	0750	1400	6.17	1510	------
−40	0910	1030	1.33	1145	Less than 2 hours cold soak
−40	0910	1400	4.83	1515	------
−46	0930	1030	1.00	1155	Less than 2 hours cold soak
−46	0930	1400	4.50	1520	------

*Temperature registered by the ten thermocouples mounted in the tunnel on the windward side of the shelter.

**Duration of cold soak at designated temperature.

FIG. 9 SHOWS THE IDENTIFICATION OF THE SHELTER-SECTION NUMBER 2T, AS WELL AS THE AIRDUCT MANIFOLD AND FOUR CHECK INTAKE VALVES.

any damage and in appearance it could be compared with that shown under the ambient room temperature of 21°C (70°F). The test results and observations made on the shelter in the afternoon test were about the same as those obtained in the morning run.

At −29°C (−20°F): The shelter was much stiffer than it was at −18°C. The shelter was more difficult to handle. However, no undue difficulty was experienced in rolling up the shelter to measure its volume. The package volume of the shelter was appreciably larger than it was at −18°C. The coating on the skin has begun to crack and peel and some of the strapping delaminated. Some of the cracks, peeling of the coating, and delamination of the strapping are shown on Figure 10. One wedge at the base of the shelter separated from the outer shell in the afternoon test. An examination of the adhesive on this wedge, shown on Figure 11, indicated that it was quite brittle. The shelter would not remain inflated more than one hour. This may have been due to the diaphragms in the manual check valves which show a tendency to curl when exposed to extreme cold, causing them to not seat properly, or to the cracking of the coating on the bladder, or both. The shelter was tested twice at this temperature.

At −40°C (−40°F): The shelter was very stiff and it was not possible to fully inflate it before testing. The shelter was very difficult to roll up. The package volume increased appreciably over what it was at −29°C (−20°F). During the roll-up a patch came loose (shown on Figure 11). An examination indicated that the adhesive was quite brittle. The first major separation of the cemented areas occurred. This was in the area adjacent to the transition opening on the manifold side and vertically along cell #10. See Figure 12. Foam insulation became very stiff and difficult to fold. The separation began at this seam and occurred during the handling or working of the shelter in preparation for the folding or rolling up of the shelter section to determine its storage volume.

Further examination of the shelter revealed that additional amounts of strapping were coming loose and the surface on which the adhesive was applied appeared glassy and brittle. Indications are that the adhesive Bostik 1095/9 becomes brittle at −40°C and seams bonded with this adhesive have a higher propensity to separate during handling at this temperature than do seams bonded with Bostik adhesive 1039/5. It was found impossible to reinflate the shelter even with the use of two blowers.

At −46°C (−50°F): The seam stiffness and storage volume were measured twice and the shelter section rolled up twice at this temperature. It could not be erected at this temperature even when two blowers are used. The material was very stiff and the storage volume increased noticeably. During the last roll-up operation, a portion of the ground sod cloth assembly, on the side opposite the manifold, delaminated completely for a length of approximately 1.2 m (4 ft), Figure 13. The delamination probably resulted from the rolling operation causing a breakdown of the adhesive bond at this low temperature. Additional cracks in the outer coating and delamination of the coating from the base fabric was also observed. It appears that the rolling-up operation and the removal

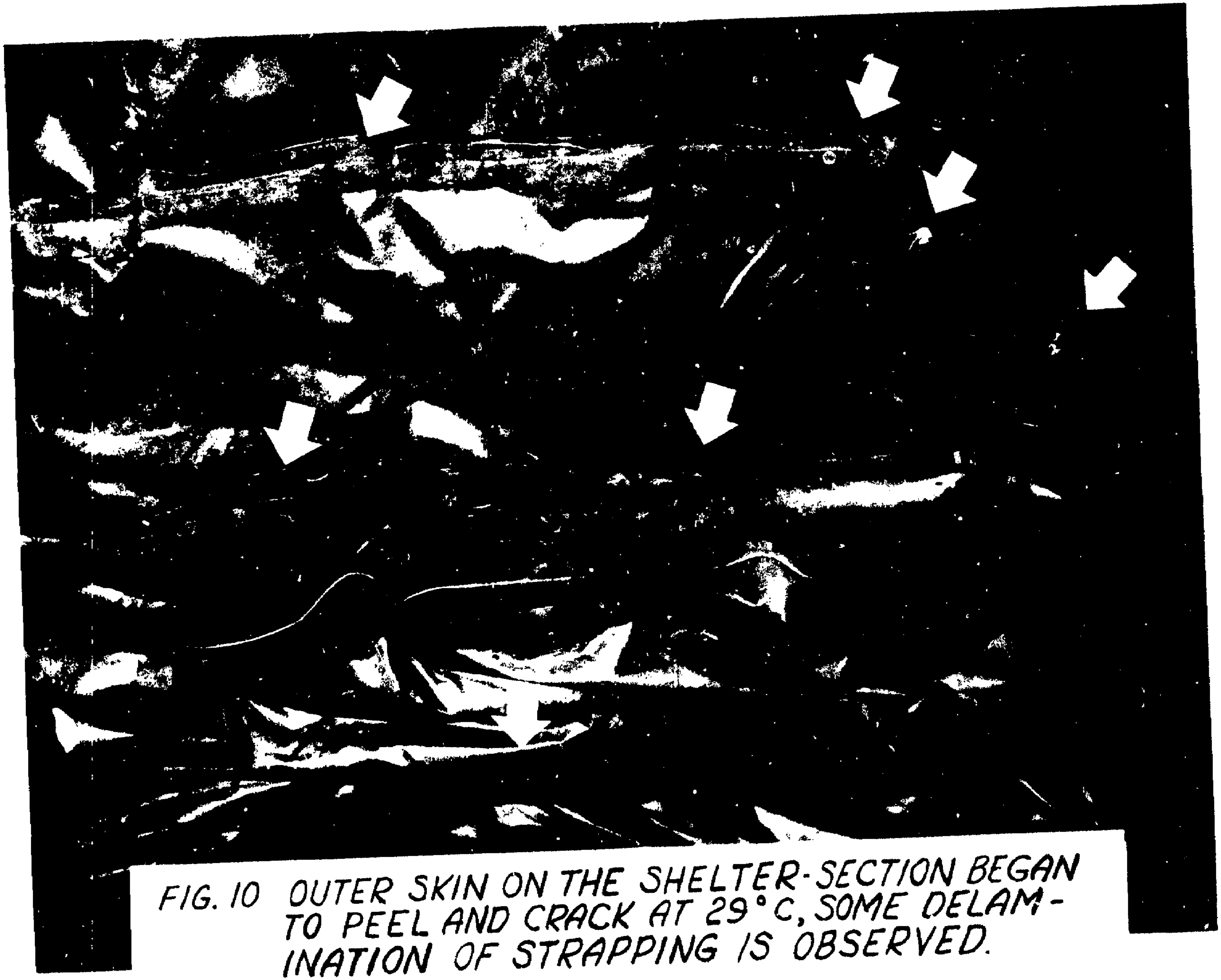

FIG. 10 OUTER SKIN ON THE SHELTER-SECTION BEGAN TO PEEL AND CRACK AT 29°C, SOME DELAMINATION OF STRAPPING IS OBSERVED.

FIG. 11 - WEDGE WHICH SEPARATED FROM OUTER SHELL AT -29°C AND PATCH WHICH SEPARATED FROM INNER SHELL AT -40°C

FIG. 12 MAJOR SEPARATION OF CEMENTED SEAM VERTICALLY ALONG CELL NUMBER 10

FIG. 13 SEPARATION OF SEAM IN SOD CLOTH ON SIDE OPPOSITE THE MANIFOLD

of air from the shelter sections at this low temperatury is extremely hard on the fabric and its adhesive bonds and is considered to be as severe as any use in the field.

Shelter Section Number 3N (Bostik 1039/5):

The cold chamber test on the MUST corridor connectors showed that the shelters did not meet the military requirements to be operational at −46°C (−50°F). The shelter sections tested could not be erected at either −40°C (−40°F) or at −46°C (−50°F). Since the material in the shelters tested was suspected of not meeting the specification requirements, it was decided to make an additional test using another shelter from current production from another contractor. The shelter selected was a MUST ward unit. This shelter is of the same material, construction, and size as the two corridor connectors tested except that it does not have the two side openings. The MUST ward unit was further modified by replacing two of its bladders with two others. One bladder was taken from a MUST unit fabricated before 1968; the second bladder was taken from a corridor connector from current production. The ward section selected is designated as Shelter Section Number 3N. This shelter was subjected to the simulated solar heat test conducted at NBS in December 1974.

The shelter sustained some minor discernible defects as a result of the NBS test. The defects were as follows:

a. Four of the ten strappings showed minor delaminations called "tunneling." The largest of the tunneling delaminations occurred on strapping number 8 and was 0.1 m (4 in) long, probably due to crooked stitching. Three other strappings exhibited tunneling up to 0.013 m (1/2 in). The tunneling found usually occurred around wrinkled areas on the exterior fabrics. This would indicate a manufacturing fault rather than the fault occurring as a result of usage of the shelter section.

b. Six of the thirteen valve ring collars showed minor delaminations. The delaminations were no greater than 0.014 m (1/2 in) in width and 0.025 m (1 in) in depth. See Figure 14. Also, 8 out of 76 patches on the shelter showed delamination varying from 10% to 30% of the bonded surface area. See Figures 15 and 16. Except for these minor deficiencies the overall appearance of the shelter was very good. The shelter was suitable to use for the controlled cold temperature test.

The actual temperature of the test chamber, time and duration of the testing cycle, and the cold soak period at the designated temperature for this shelter were as given on Table 5.

TABLE 5

The Actual Temperature of the Test Chamber, Time and Duration of the Testing Cycle, and the Cold Soak Period of the Shelter Section Number 3N

Test Temp* (°C)	Time Attained Hours	Start Test Hours	Cold Soak Hours**	Comp Test Hours	Comments
20	0645	1030	3.75	1130	Ambient 21°C (70°F)
20	0645	1330	6.75	1425	———
−18	0815	1030	2.20	1130	−18°C (0°F)
−18	0815	1330	5.25	1420	———
−29	0745	1030	2.75	1120	−29°C (−20°F)
−29	0745	1330	5.75	1435	———
−40	0750	1039	3.67	1135	−40°C (−40°F)
−40	1750	1330	6.67	1430	———
−46	0745	1030	3.75	1130	−46°C (−50°F)
−46	0745	1330	6.75	1425	———

*Temperature registered by the ten thermocouples mounted in the tunnel on the windward side of the shelter.

**Duration of cold soak at designated temperature.

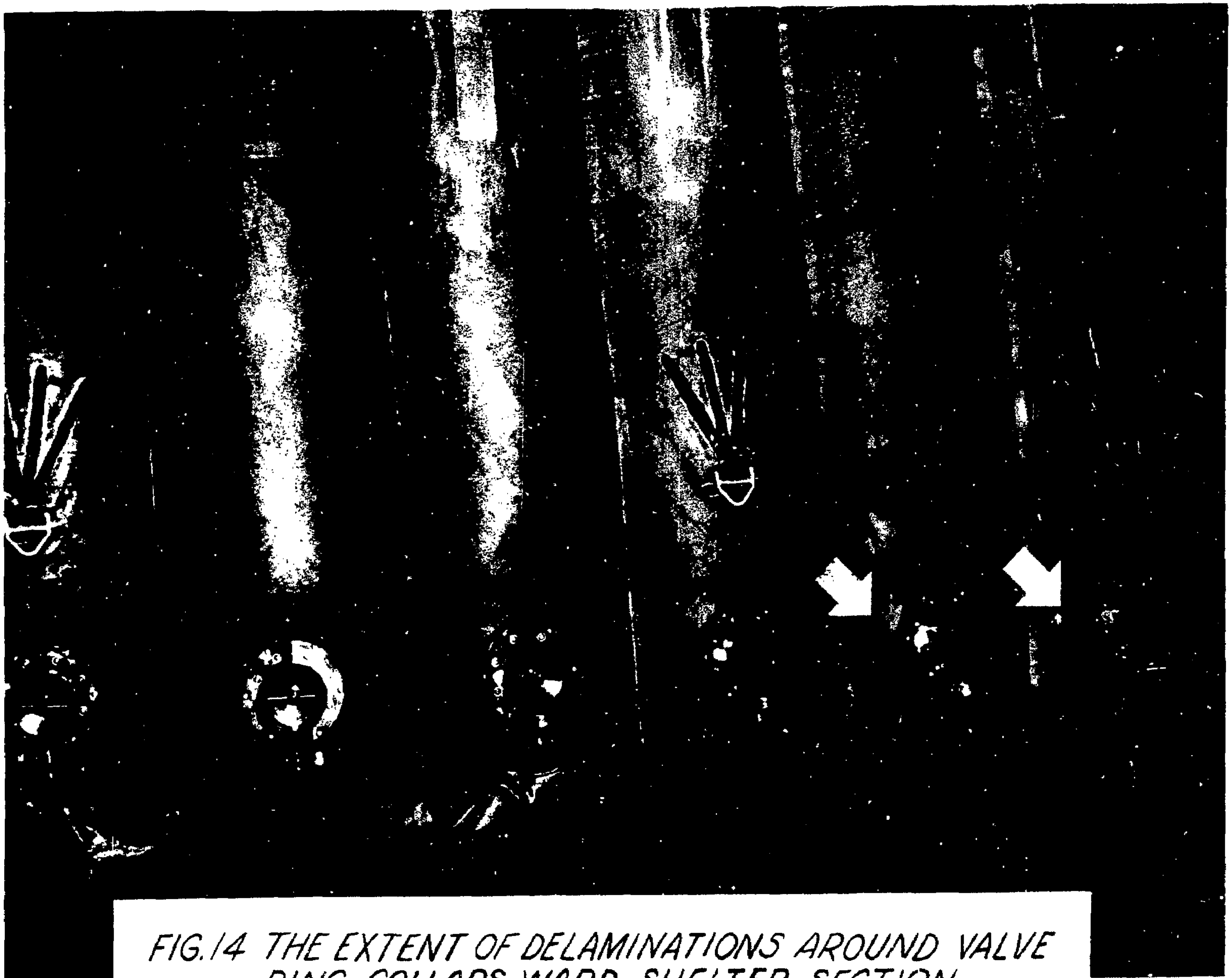

FIG. 14 THE EXTENT OF DELAMINATIONS AROUND VALVE RING COLLARS–WARD SHELTER SECTION

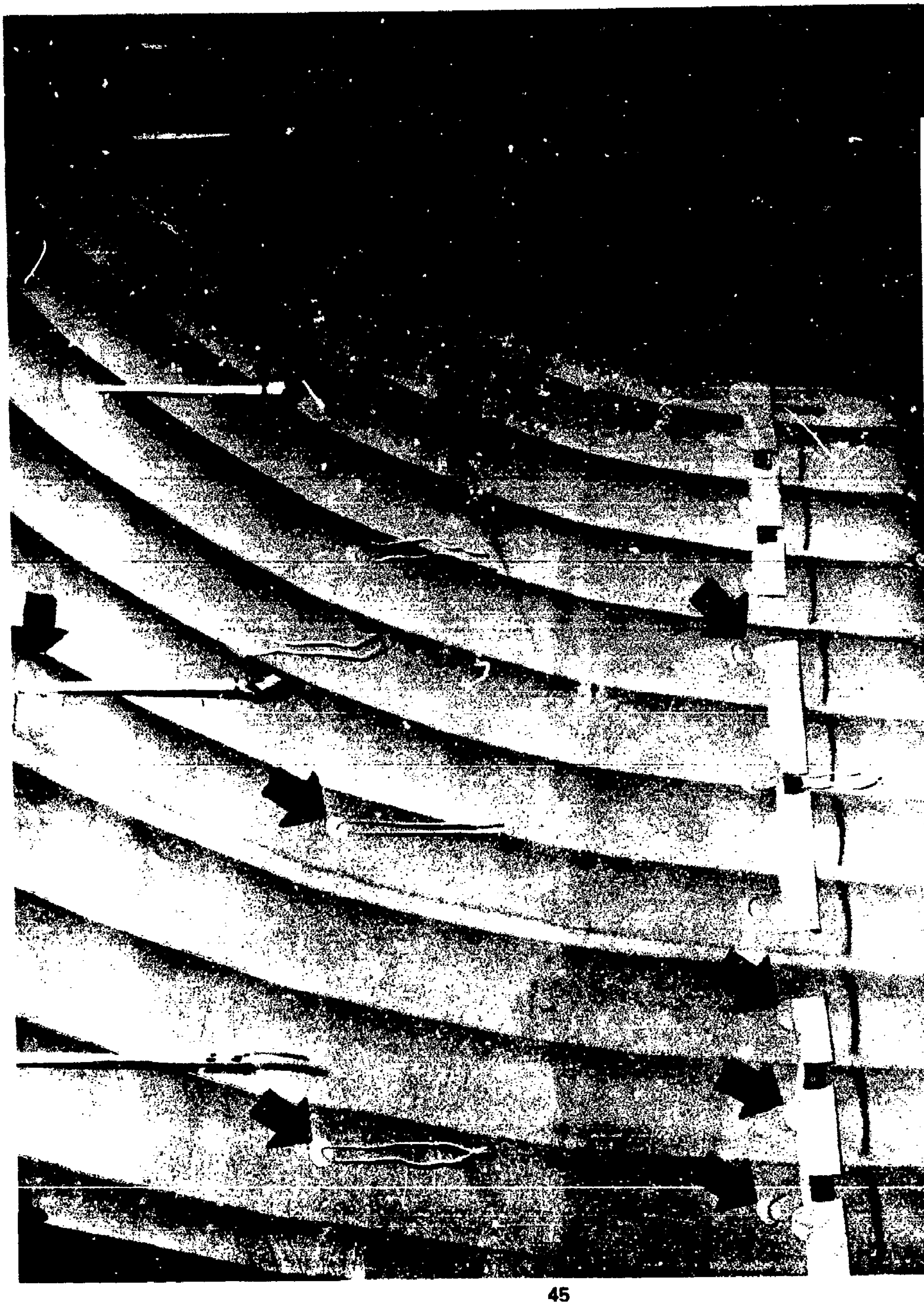

FIG. 15 DELAMINATION OF INTERIOR PATCHES ON WARD SHELTER SECTION LEFT WALL.

FIG. 16 DELAMINATION OF INTERIOR PATCHES ON WARD SHELTER SECTION RIGHT WALL.

It should be noted from Table 5 that the cold soak time of the shelter at the designated temperature exceeded the desired minimum of two hours before testing. The main objective of this test was to determine whether the ward unit, after following the initial test procedure, could be reinflated at −46°C (−50°F). Therefore, this shelter was subjected at each temperature to a cycle of inflate, deflate, force out the air in the tubes, roll up, unroll, and reinflate. No measurements were made for relative seam stiffness or relative storage volume at the low temperatures of this shelter section.

The ward unit maintained its good appearance, as exhibited at the ambient temperature of 21°C, throughout the low temperature test. No further delamination of either the strapping or patches was observed during the conduct or at the completion of the test. As expected, the fabric of the outer casing increased in stiffness as the temperature decreased. No significant changes in the appearance of the shelter were noticed at −18°C (0°F) or at −29°C (−20°F). However, at −40°F (−40°F) the cell containing the bladder taken from the corridor connector was soft; it apparently could not retain air. However, the shelter could be inflated and erected at −40°C, and again at −46°C; all the other bladders in the shelter were able to sustain the full blower pressure. The bladder taken from production prior to, or about, 1968 is know to conform to the specifications for the shelter unit since this bladder material formed the basis for the current specifications. From the fact that all the other bladders, except that from the corridor connector, inflated and retained sufficient air pressure to erect the shelter, it can be assumed that the bladder material in shelter 3N did meet the specification requirements for the bladder material. The bladder taken from the corridor connector could not retain the air at blower pressure at −40°C and therefore may not be of the same material as the other bladders and may not meet the bladder material specifications. The three bladders from different manufacturers will be further investigated and the results will be furnished in a separate report.

At the completion of the cold temperature test the MUST shelter section was still serviceable. There appeared to be no observed cracking or peeling of the coating of the external fabric and no further delamination of strapping or patches other than those reported at the start of this test.

This shelter section has withstood both the simulated solar heat tests at NBS and the cold temperature test at NARADCOM and apparently is still suitable for field use. This was not the case with the first two MUST corridor connectors tested at NARADCOM.

TEST RESULTS

Two tests were performed on the deflated shelter in the test chamber at each designated temperature, namely at 21°C (70°F), −18°C (0°F), −29°C (−20°F), −40°C (−40°F) and −46°C (−50°F).

RELATIVE SEAM STIFFNESS TESTS:

The seam stiffness test was performed on the lap seam in the floor of the shelter* and on the strapped double feld seam on the end closure panel of the shelter.**

This is the first time an attempt was made to measure the relative seam stiffness on a full size shelter. The procedure is clear but the question of the weight to use presented a problem. To resolve this question, three weights were used, namely 0.97 kg (2.1 lb), 2.3 kg (5 lb) and 4.5 kg (10 lb).

The test data obtained on relative seam stiffness for lap seams is shown on Table 6 and for the double feld seams on Table 7.

It can be seen from Tables 6 and 7 that the increasing stiffness with the lowering in temperature was demonstrated by the use of the three weights (the higher the number, the greater the relative seam stiffness). However, in the conduct of the test, it was found that the heavier weights were the easiest to use. It is therefore recommended that in future tests for relative seam stiffness on this type of shelter only one weight should be used, namely 4.5 kg.

In Figures 17 and 18 only the seam stiffness test with 4.5 kg are shown.

RELATIVE STORAGE VOLUME:

The relative storage volume of the shelter sections at low temperature are shown on Table 8 and on Figure 19. Again, it can be seen that the storage volume becomes greater as the temperature gets colder. In fact, at minus 45°C the storage volume of the two shelters is about or more than double the storage volume at room temperature.

*2-inch cemented lap seam (no stitching).

**Fed Std 751 stitch class 301, seam type L5c-2, 1/2-inch double feld seam

TABLE 6

Relative Seam Stiffness

Lap Seam
Test Weight

Temp (°C)	0.97 kg Shelt 1A (cm)	0.97 kg Shelt 2T (cm)	2.3 kg Shelt 1A (cm)	2.3 kg Shelt 2T (cm)	4.5 kg Shelt 1A (cm)	4.5 kg Shelt 2T (cm)
21	0.70	1.26	0.48	0.85	0.30	0.70
−18	1.23	2.25	0.80	1.30	0.50	0.80
−29	1.80	3.80	1.15	2.18	1.25	1.17
−40	4.15	4.50	2.55	3.46	1.35	2.38
−46	4.23	6.62	3.15	4.15	1.90	3.30
21	0.75	1.45	0.50	0.98	0.35	0.68

TABLE 7

Relative Seam Stiffness

Double Feld
Seam Test Weight

Temp (°C)	0.97 kg Shelt 1A (cm)	0.97 kg Shelt 2T (cm)	2.3 kg Shelt 1A (cm)	2.3 kg Shelt 2T (cm)	4.5 kg Shelt 1A (cm)	4.5 kg Shelt 2T (cm)
21	0.83	1.26	0.47	0.85	0.48	0.70
−18	1.45	2.25	1.18	1.30	0.78	0.80
−29	3.15	3.80	1.15	2.18	0.92	1.17
−40	7.45	4.50	5.12	3.46	2.65	2.38
−46	10.11	6.62	8.08	4.15	4.10	3.30
20	0.80	1.45	0.60	0.98	0.50	0.68

TABLE 8

Relative Storage Volume of the Two Corridor Connectors

Temperature (°C)	Shelter 1A (m^3)	Shelter 2T (m^3)
21	3.66	5.32
–18	4.68	6.45
–29	5.29	7.48
–40	7.90	10.31
–46	9.63	10.42
21	3.66	5.50

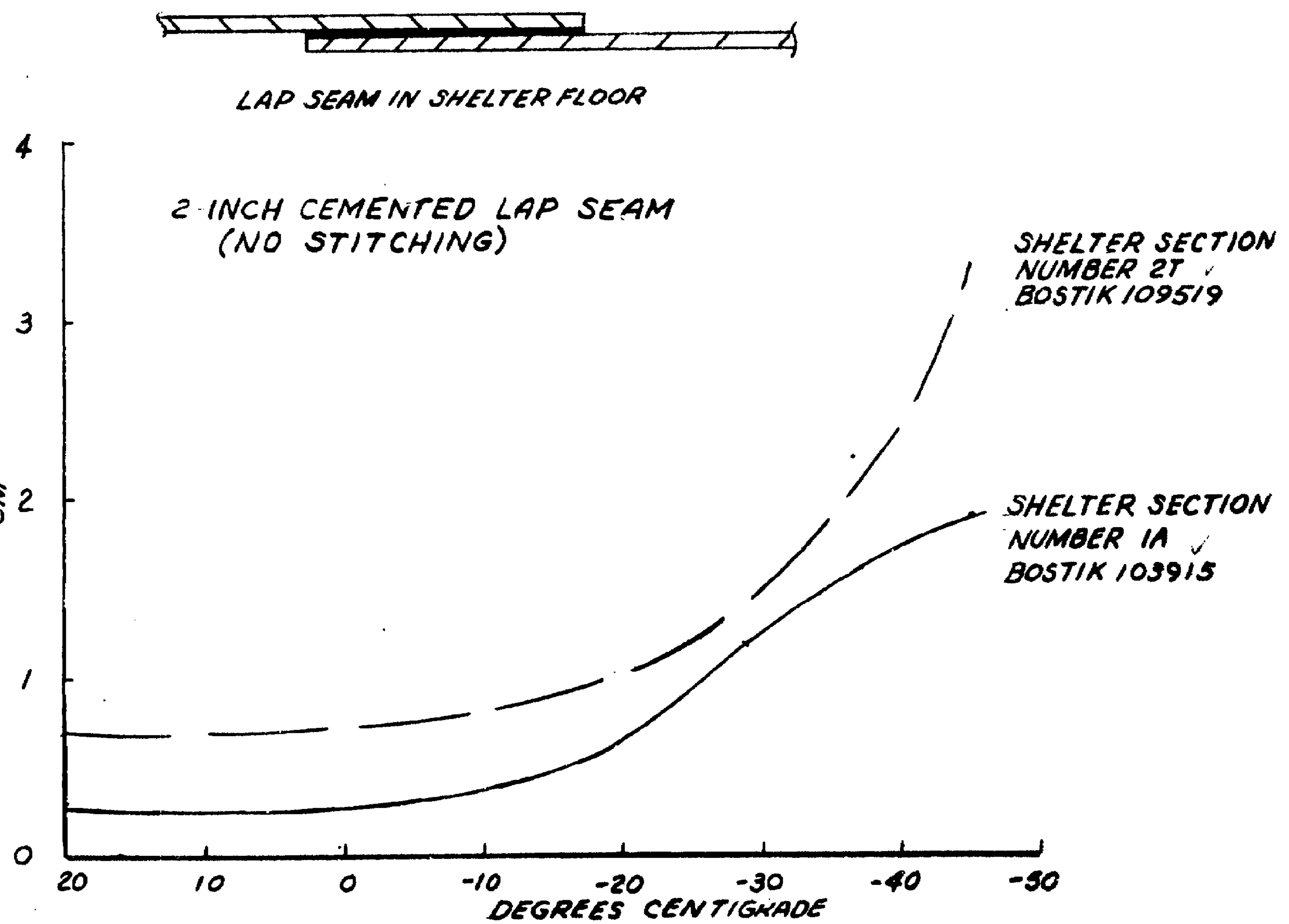

FIG. 17 RELATIVE SEAM STIFFNESS OF LAP SEAMS (4.5 Kg WEIGHT)

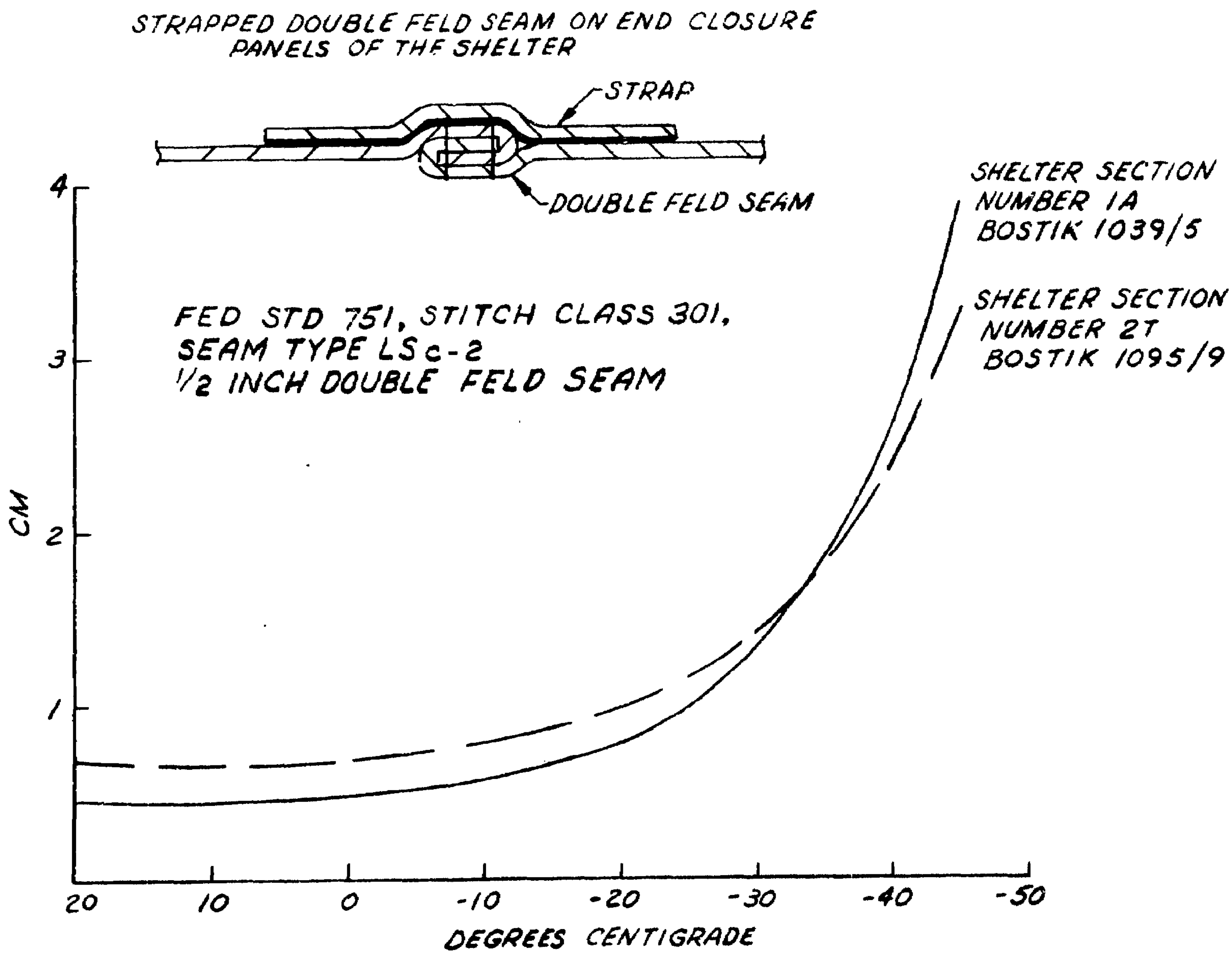

FIG. 18 RELATIVE SEAM STIFFNESS OF STRAPPED DOUBLE FELD SEAMS (4.5 Kg WEIGHT)

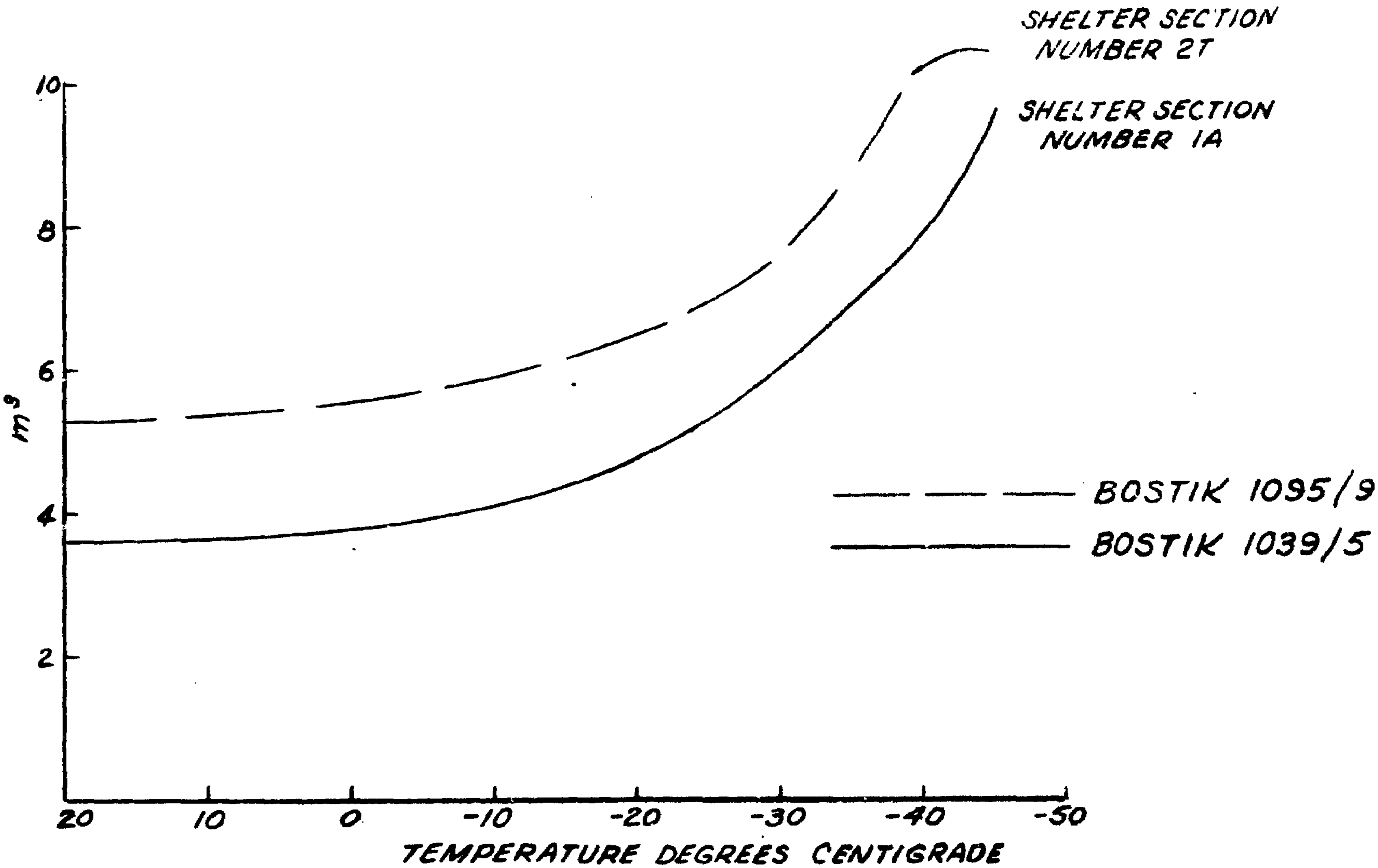

FIG. 19 RELATIVE STORAGE VOLUMN OF THE TWO CORRIDOR CONNECTORS.

CONCLUSIONS AND RECOMMENDATIONS

Both adhesives, Bostik 1039/5 and Bostik 1095/9, can be used successfully in bonding the seams in MUST shelters for cold weather use. Adhesive 1095/9 is stiffer and more brittle when subjected to cold temperatures than adhesive 1039/5. The stiffness of adhesive 1095/9 under cold weather conditions is reflected in a greater storage volume for shelters with seams bonded with Bostik 1039/5 adhesive (2/3 greater volume).

The brittleness of Bostik 1095/9 under cold temperature conditions makes the seams and patches bonded with this adhesive more susceptible to separation during the manipulation necessary to pitch and strike the shelter than with similar bonds made with Bostik 1039/5 adhesive.

It is recommended that with storage space for shelters at a premium in the MUST system consideration be given to using only the Bostik 1039/5 adhesive or equal in future procurements of the inflatable shelters for the MUST hospital units. The selection of Bostik 1039/5 has the added advantage that it does not become as stiff or brittle as Bostik 1095/9 in cold weather. Therefore, the seams in the shelter are less susceptible to separation during the necessary action of pitching and striking the shelter in cold weather.

APPENDIX A

COLD TEMPERATURE TEST, MUST INFLATABLE SHELTERS

APPENDIX A

Cold Temperature Test
MUST Inflatable Shelters

Sir Hubert Wilkens Arctic Test Chamber, NARADCOM

Objectives

There are two objectives to be achieved in this test as follows:

1. Determine the effect of cold temperatures on the relative seam stiffness of a MUST shelter in which the adhesive used was Bostik 1095/9 with the seams of a MUST shelter in which the adhesive used was Bostik 1039/5.

2. Determine the effect of cold temperatures on folding the shelters for storage and the bulk volume of the folded shelter.

3. Test Items: Two shelters will be tested as follows:

   a. An inflated shelter which is fabricated using 100% Bostik 1039/5 adhesive.

   b. An inflated shelter which is fabricated using 100% Bostik 1095/9 adhesive.

4. Test Temperatures:

   Each shelter will be tested in the Arctic Test Chamber of the Climatic Laboratories at NARADCOM under four different cold temperature conditions, namely −18°C (0°F), −29°C (−20°F), −40°C (−40°F) and −46°C (−50°F).

Test Procedures

1. The shelter shall be inflated under ambient conditions, 21°C (70°F) ± 5°C (10°F). The shelters shall be inspected for visible defects; all such defects shall be noted and will be included in the test report. The shelter shall then be deflated and the stiffness of seams evaluated (paragraph 2, below).

2. Relative Seam Stiffness Test:

   a. Test Equipment:

      (1) Wood board, temperature conditioned before use – 0.6 m (24 in) x 0.6 m (24 in) x 0.02 m (3/4 in).

(2) Three weights as follows: by actual weight 0.97 kg (2 lb), 2.3 kg (5 lb), and 4.5 kg (10 lb). All weights shall be temperature stabilized before use.

(3) Steel rule, 0.0016 m (1/16 in) divisions, 0.3 m (12 in) long.

b. Conditions for Test:

(1) All stiffness tests are to be performed under the testing temperatures.

(2) Under cold temperature conditions all test personnel must wear gloves when handling the shelter.

c. Test Procedure:

(1) The 0.6 m (24 in) x 0.6 m (24 in) board is placed on the floor in a position to allow a portion of the ground cloth to be placed on it. With the shelter deflated, one lap seam of the ground cloth is folded back on itself. The folded seam is centered and placed perpendicular to the long edge of the board. The edge (loop) of the folded seam is positioned two inches from the free edge of the board. With the folded seam so positioned on the board, carefully place a 0.97 kg (2 lb) weight on the loop of the folded seam. The full load of the weight should be supported by the loop of the folded seam. With the weight in place, measure the height of the loop from the board to the top surface of the loop. The height of the loop shall be reported in appropriate metric units. The 0.97 kg (2 lb) weight shall be removed from the folded seam loop and replaced with a 2.3 kg (5 lb) weight. The height of the loop under the 2.3 kg weight is measured and reported in appropriate metric units. The 2.3 kg weight is removed from the loop of the folded seam and replaced with a 4.5 kg (10 lb) weight. The height of the loop of the folded seam under the 4.5 kg weight is measured and reported in appropriate metric units. The test is completed with the removal of the 4.5 kg weight.

(2) With the shelter deflated, the seam stiffness test should be repeated on the strapped double-feld seam on the end closure panel of the shelter.

(3) After the seam stiffness test is completed, the deflated shelter shall be folded for transport or storage. The width, length, and height of the shelter shall be measured in feet and the bulk or storage volume of the shelter calculated as follows:

$$\text{With (m)} \times \text{Length (m)} \times \text{Height (m)} = \text{Storage Volume (m}^3\text{)}$$

(4) The test shelter shall be placed in the test chamber with one arch side on the floor of the chamber. The shelter shall then be pressurized with sufficient pressure to insure the shape integrity of the shelter. This pressure shall be maintained throughout the test period.

(5) Lower the internal temperature of the chamber to −18°C (0°F) and maintain this temperature until temperature stabilization of the test shelter is reached. (24 hours is suggested for temperature stabilization of the shelter from ambient conditions to −18°C (0°F). When temperature stabilization has been achieved, deflate the shelter and maintain the chamber temperature at −18°C. Repeat the procedures outlined in paragraphs 2c(1), (2) and (3), above, at −18°C.

(6) Maintaining the chamber temperatures at −18°C (0°F), the shelter is reinflated as in paragraph (4), above. The shelter is allowed to temperature stabilize at −18°C. (One hour is suggested for temperature stabilization of the shelter for this repeat test). When temperature stabilization has been achieved, repeat the procedures outlined in paragraphs 2c(1), (2) and (3), above.

(7) The shelter shall be pressurized in accordance with paragraph (4), above. The shelter shall be examined for visible defects. Any visible defect noted will be included in the test report.

(8) With the shelter inflated, the chamber temperature is lowered from −18°C (0°F) to −29°C (20°F). The shelter is allowed to stabilize at the lower temperature. When the temperature stabilization of the shelter has been achieved at −29°C, repeat the procedures outlined in paragraphs 2c(2), (3), (5), (6) and (7), above.

(9) With the shelter inflated, the chamber temperature is lowered to −40°C (−40°F). The shelter is allowed to stabilize at the lower temperature. When the temperature stabilization of the shelter is achieved at −40°C, repeat the procedures outlined in paragraphs 2c(2), (3), (5), (6) and (7), above.

(10) With the shelter inflated, the chamber temperature shall be lowered from −40°C (−40°F). The shelter is allowed to stabilize at the lower temperature. When temperature stabilization of the shelter is achieved at −46°C, repeat the procedures outlined in paragraphs 2c(2), (3), (5), (6) and (7), above.

(11) Bring the temperature of the chamber to ambient. Deflate and fold the shelter for storage. Remove the shelter from the chamber and relocate the shelter to an area where it could be reinflated. Pressurize the shelter at ambient temperature, 21°C (70°F) ± 5°C (10°F). Allow the shelter to stabilize to the ambient temperature. Examine the shelter for visual defects. The visual defects noted shall be included in the test report.

(12) The second test shelter shall be tested in accordance with paragraphs (1) through (11), as noted above.

APPENDIX B

COMPARISON OF BOSTIK 1095/BOSCODUR 9 AND BOSTIK 1039/BOSCODUR 5 ADHESIVES AS RELATED TO MUST INFLATED SHELTER SECTIONS

CONVERSION FACTORS

1 Pound-Mass (1 bm avoirdupois = 0.454 kilogram (kg))

Degree Fahrenheit to Degree Celsius – $t°_C = (t°_F - 32)/1.8$

STSNL–CCP 10 April 1974

MEMO FOR RECORD

SUBJECT: Comparison of Bostik 1095/Boscodur 9 and Bostik 1039/Boscodur 5 Adhesives, as Related to MUST Inflated Shelter Sections

1. Subject comparison is furnished in attached Tables I to IV (Incl 1). It is intended to shed light (insofar as may reasonably be done by laboratory tests) on the performance to be expected of adhesive 1095/9 under field conditions and this to provide an alert in the event of discovery of any weakness in performance.

2. Inspection of the tables indicated the following:

a. Both adhesives pass the 40 lb. dead load shear test at 200 F.

b. The adhesives are nearly equal at 1 lb. dead load peel at room temperature.

c. In the 2 lb. dead load peel at room temperature, 1039/5 performs appreciably better than 1095/9.

d. Bostik 1095/9 is appreciably stiffer than 1039/9 at temperatures from 70 F to minus 50 F.

3. Evaluation of Results:

a. Performance of 1095/9 at elevated temperatures is a little less than that of 1039/5 but its suitability in this respect is not questioned in view of good results obtained in the NB of S solar load tests of shelter sections.

b. Adhesive 1095/9 at low temperatures is appreciably stiffer than 1039/5, in laboratory test. These results cannot be translated into effects on shelters in the field. It is believed that cracking of the adhesive will not occur in the field since folds as sharp as the rolled folds in laboratory tests will probably not occur in the field. However, the increased stiffness may affect the cubage of the packed shelter, even though the adhesive covers only about 5 percent of total coated fabric suface.

4. Recommendations:

It is recommended that shelters coming off production lines using 1095/9 adhesive be subject to low temperature unpacking, inflation, and repacking, in comparison with corresponding shelters made with 1039/5 adhesive.

1 Incl
as

CARL J. FRENNING/cg/2611
Adhesive Group, C&PLSEL

TABLE I

Dead Load Shear Test (40# – 4 Hours – 200°F)

Results are given in inches of slippage.

All tests were conducted on outer casing coated fabric from Inflated Products Co.

Bostik Adhesive 1039/5			Bostik Adhesive 1095/9	
Ratio of Base to Accelerator			Ratio of Base to Accelerator	
16/1	25/1*	32/1	8/1**	16/1
None	< 1/32	< 1/32	< 1/32	< 1/64

*The ratio used by Garrett Corp. per its submitted Technical Data Package was 25 to 1.

**The ratio recommended by Bostik Div, and the ratio indicated in NLABS Data Package for 1974 procurement is 8 to 1.

TABLE II

Dead Load Peel Test – 10 Minutes Duration

Results are given in inches of peel at end of test.
All tests were conducted on outer casing coated fabric from Inflated Products Co.

Bostik Adhesive 1039/5			Bostik Adhesive 1095/9	
Ratio of Base to Accelerator			Ratio of Base to Accelerator	
16/1	25/1*	32/1	8/1**	16/1
Test at 2 lb per inch load, at room temperature				
1–1/2	1–1/8	1–3/8	Run off completely in 6 seconds	Ran off completely in 70
Test at 1 lb per inch load, at room temperature				
< 1/16	< 1/16	< 1/16	1/16	1/16
Test at 1 lb per inch load, at 200 °F				
< 1/8	< 1/8	15/16	3/4	9/16
3/8	11/16	7/8		

*The ratio used by Garrett Corp. per its submitted Technical Data Package was 25 to 1.

**The ration recommended by Bostik Div and the ratio included in NARADCOM data package for 1974 procurement is 8 to 1.

TABLE III

Low Temperature Flexibility of Cast Neoprene Adhesives

Established Procedure:

	Thickness	Room Temperature	0°F	–20°F*	–40°F**
Bostik 1095/9 8 to 1 ratio) Sample H1	7.5 to 15 mil	11.6 cm	16.7 cm	18.7 cm	21.3 cm
Bostik 1095/9 8 to 1 ratio) Sample H2	6.2 to 11.5 mil	9.5 cm	16.0 cm	19.2 cm	21.2 cm
Bostik 1039/5 25 to 1 ratio) Sample H3	5.5 to 9.5 mil	5.6 cm	7.9 cm	8.1 cm	8.3 cm
Bostik 1039/5 25 to 1 ratio) Sample H4	6.0 to 11.5 mil	7.8 cm	9.4 cm	9.6 cm	9.7 cm

*Sample of Cast Bostik 1095/9 was flexed by gloved hands at –20°F and –40°F. It cracked.

**Sample of Cast Bostik 1039/5 was flexed by gloved hands at –20°F and at –40°F. It was OK (no cracking).

TABLE IV

Flexibility of Adhesive-Brushed Coated Fabric

Coated Fabric:	Outer casing.		
Adhesives:	Bostik 1095/Boscodur 9	Ratio	8/1
	Bostik 1039/Boscodur 5	Ratioo	25/1

Application: Two brush coats of mixed adhesive applied to Face (Hypalon) and to Back (Neoprene). Total Four Coats Laminated to form specimen for Peel Test.

Film Thickness: Dried Film .006" to .015".

Test Method: Flexing and kneading by hand.

	R.T. 70-75 F.	0°F.	–20°F.	–40°F.
Lamination 2 Fabrics plus Film 1095/9	Flexible	Boardy	Small cracks	Large cracks
Lamination 2 Fabrics, plus Film 1039/5	More Flexible	Less Boardy	Boardy- No cracks	Boardy- No cracks
1 Fabric (Neoprene), plus Film 1095/9	Flexible	Stiff	Cracks	Large cracks
1 Fabric (Neoprene), plus Film 1039/5	More Flexible	Less Stiff	Stiff- No cracks	Boardy- No cracks
Dried Film 1095/9	Flexible	Semi-rigid	Cracks- Breaks	Shatters when folded.
Dried Film 1039/5	More Flexible	Flexible	Boardy	No cracks when folded.

US ARMY NATICK RESEARCH AND DEVELOPMENT COMMAND

Stiffness of MUST Adhesives at Low Temperatures

Adhesives used to assemble the MUST shelters are cast as a film to check low temperature flexibilities. The adhesives, Bostik 1039/5 and 1095/9 were cast as films by C. Frenning, allowed to dry and age for a minimum of one week and STE for flexibility in accordance with Method 5204 of FTM STD. 191. The samples were also flexed by hand to determine the temperature at which they would crack. Results are as follows:

	Thickness	Room Temp	0°F	20°F*	–40°F**
(Bostik 1095/9) Sample #1	(0.0075 to 0.0150)	11.6 cms	16.7 cms	18.7 cms	21.3 cms
(Bostik 1095/9) Sample #6	(0.0065 to 0.0115)	9.5 cms	16.0 cms	16.0 cms	21.2 cms
(Bostik 1039/5) Sample #3	(0.0055 to 0.0095)	5.6 cms	7.9 cms	8.1 cms	8.3 cms
(Bostik 1039/5) Sample #4	(0.006 to 0.0115)	7.8 cms	9.4 cms	9.6 cms	9.7 cms

Sample of cast Bostik 1095/9 cracked when flexed at –20°F.
Sample of cast Bostik 1039/5 O.K. when flexed at –20°F.

Sample of 1095/9 cracked when flexed at –40°F.
Sample of 1039/5 O.K. wnen flexed at –40°F.